

# Field Theory of Gravitation: Desire and Reality

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## Abstract

A retrospective analysis of the field theory of gravitation, describing gravitational field in the same way as other fields of matter in the flat space-time, is done. The field approach could be called "quantum gravidynamics" to distinguish it from the "geometrodynamics" or general relativity. The basic propositions and main conclusions of the field approach are discussed with reference to classical works of Birkhoff, Moshinsky, Thirring, Kalman, Feynman, Weinberg, Deser. In the case of weak fields both "gravidynamics" and "geometrodynamics" give the same predictions for classical relativistic effects. However, in the case of strong field, and taking into account quantum nature of the gravitational interaction, they are profoundly different. Contents of the paper: 1) Introduction; 2) Two ways in gravity theory: 2.1.Hypotheses of Poincaré and Einstein, 2.2. Gravity as a geometry of space, 2.3. Gravitation as a material field in flat space-time; 3) Classical theory of tensor field: 3.1.Works of Birkhoff and Moshinsky, 3.2.Works of Thirring and Kalman, 3.3.Thirring and Deser about identity of GR and FTG; 4) Quantum theory of tensor field; 5) Modern problems in field theory of gravitation: 5.1.Multicomponent nature of tensor field, 5.2.Choice of energy-momentum tensor of gravitational field, 5.3.Absence of black holes in FTG, 5.4.Astrophysical tests of FTG; 6) Conclusions.

## 1 Introduction

There is a common statement both in scientific publications and popular literature dealing with General Relativity (GR) that geometrical description of gravity is the only logically consistent generalization of the Newtonian classical theory of gravitation. However, a reader, non-aligned to general relativity may put a natural question why it is impossible to consider gravitation in the same way as other physical interactions, i.e. as a quantum field in flat space-time background.

Indeed, such a field approach to gravity has been discussed in the literature and known since the works of Poincaré in 1905-1906 on the special theory of relativity. The Field Theory of Gravitation (FTG) was considered in classical works of Birkhoff, Moshinsky, Thirring, Kalman, Feynman, Weinberg, and Deser. The history of FTG is full of misleading claims and it demonstrates the hard way of creation and development of scientific ideas.

There are many articles and books dealing with GR but only a few papers discuss FTG. Perhaps it is a consequence of wide-spread opinion that FTG is equivalent to GR and hence we need not spend

time to study field gravity approach. This opinion comes from the basic textbooks on GR, such as Misner, Thorn, Wheeler (1973), ch. 18, and Zel'dovich, Novikov (1971), ch. 2, where it is asserted a possibility for derivation of GR from tensor field theory of gravitation and hence the same physical meaning of both theories. Indeed in papers of Thirring(1961) and Deser (1970) there were claims that field theory approach is identical with the geometrical one and there are no gravitational effects which could provide grounds to distinguish between them.

Certainly, this natural desire to justify geometrization via field theory approach (i.e. utilizing common basis with other physical interactions) is very clear. However, as it will be shown here, reality turns out to be much more complex and interesting. Actually GR and FTG are two alternative theories with different bases and different observational predictions. Of course, for the weak gravitational fields, which are available for experiments now, both theories give the same values of the classical relativistic effects, but they profoundly differ in the case of strong gravity, which will be obtainable in near future. Astrophysical observations of double pulsars, massive compact objects in double X-ray sources (the so called "black holes candidates"), active galaxy nuclei, gravitational waves and large scale distribution of matter in the Universe will help to check these theories in strong gravity limit.

In the present paper we shall discuss main postulates, results and problems of field gravity theory in historical perspective and in comparison with general relativity.

## 2 Two ways in gravity theory

### 2.1 Hypotheses of Poincaré and Einstein

As early as 1905 Henri Poincaré in his work "On the Dynamics of the Electron" put forward an idea to build relativistic theory for all physical interactions, including gravitation, in flat four-dimensional space. He pointed out that gravitation should propagate with the velocity of light in a retarded way — analogous to electrodynamics, and there should exist interaction mediators — gravitational waves. Several years later in his lecture on "New conceptions of matter" Poincaré wrote about inclusion of Planck's discovery of quantum nature of electromagnetic radiation in the framework of future physics. Poincaré, thus, could be rightfully regarded as the founder of that direction in theory of gravitation which now is called the quantum theory of gravitational interaction in flat space-time. This way is analogous to that of all non-gravitational physics and it came to foundations of such basic theories as quantum electrodynamics, quantum theory of weak interactions, and quantum chromodynamics. Naturally, the quantum gravodynamics or the field theory of gravitation - should take its place in this line.

In 1915 Albert Einstein published his basic equations of general relativity and thus opened another way for gravitational theory. GR treats the gravity as a curvature of the space itself caused by all non-gravitational matter, but not as a kind of material field distributed in space. Wheeler called this approach later as geometrodynamics. According to Einstein, the gravitational interaction stands aside comparing with other physical ones for which space-time is a passive background. The gravitational force is caused not by material interaction carriers, but by curvature of space, i.e. its deviation from Euclidian geometry. In fact, this means "the materialization of space", because the space can be deformed, expand and even spread in the form of gravity waves.

Thus, at the beginning of 20th century there formed two alternative ways for the theory of gravitation. The way of Poincaré — is the description of gravity as a relativistic quantum field in flat

space-time, the unique approach to all physical fields. The way of Einstein — is the reduction of gravity to space-time curvature, i.e. the statement of gravity as an exclusive among others interaction.

## 2.2 Gravity as a geometry of space

The overwhelming majority of works in gravity theory follow the way opened by Einstein. At the beginning of its development, the geometrical description of gravity was strongly motivated by the *principle of equivalence*. However as it was emphasized by Fock, strictly speaking it is not a physical but a "philosophical" principle. Indeed, there are many variants of its formulation but they cannot be tested experimentally. The real background of geometrical approach is the so called *principle of geometrisation*, according to which all gravitational phenomena can be described by the metric of the Riemann space  $g^{ik}$ . Modern achievements of GR are presented in a collection of review articles "Three hundred years of gravitation" (1987) edited by Hawking and Israel.

It should be noted that GR is a mathematically precise non-linear theory without any inner limitations to its physical applications. Thus the solutions of the Einstein's equations are considered to be physically valid both inside and outside the gravitational radius  $R_g = 2GM/c^2$ , end even up to infinite densities in singularity. Moreover geometrical approach yields the infinite gravitational force at the finite radius  $R_g$ . The infinite force cannot be balanced by any finite (non-gravitational) force and this leads to body's collapse to singularity, the so called "black hole". GR inevitably comes to existence of such exotic objects (strictly speaking mathematical ones) as black holes with infinite forces, time machines with junction between past and future, expanding universes with continuous creation of space.

The prediction of "black holes" is believed to be one of the great achievements of GR, while the problem of energy of gravitational field is considered as its "Ahill's heel" for more then 80 years. This problem is a permanent point of discussion in literature since the work of Schrödinger in 1918 in which he showed that the energy-momentum complex in GR is not a tensor (i.e. it has no definite physical value).

The roots of this problem are connected with backgrounds of geometrical approach. Actually, the flat space guaranties the conservation laws of energy, momentum and angular momentum according to Noether's theorem. This problems has been under discussion in recent years by Logunov with collaborators (see his book "Lectures on relativity theory and gravitation"). Rejection of flat space inevitably leads to fundamental difficulties with energy conservation. The famous statement from the textbook of Landau and Lifshitz (1971), ch. 11, sec. 96, is that general covariant form of energy conservation

$$T^k_{i;k} = 0 \tag{1}$$

actually "does not express any conservation law whatever", and it presents just brilliant form of energy problem in GR. Moreover, the infinite gravitational force acting at the gravitational radius of a "black hole" require infinite energy of gravitational field (of course if it exists).

Among the "standard solutions" of the energy problem in GR there are such statements as the absence of the "old" concept of energy of gravitational field, or that the gravitational energy is a non-localizable quantity. If the former takes place, it is unclear why so much efforts are devoted to build gravity wave detectors, the devices just aimed to localize gravitational energy. Non-local energy cannot be treated in quantum way, and this is a reason why there are no geometrical quantum theory of gravitation. Also this is why there are attempts to construct in the frame of GR the true energy-

momentum tensor of gravity "field" (see e.g. Babak&Grishchuk,1999). However the geometrical approach (by definition, via the principle of equivalence) excludes both gravity force and localizable energy of gravity. Hence the only way to construct the true EMT of gravity field is actually to develop the true field approach as discussed below.

## 2.3 Gravitation as a material field in flat space-time

Following the way which was pointed out by Poincaré, the classical relativistic field gravity theory has been developed by Birkhoff(1944), Moshinsky(1950), Thirring(1961), and Kalman(1961). A quantum extension of FTG was considered by Feynman(1963) and Weinberg(1965). The basis of FTG is the Lagrangian formalism of relativistic field theory, which is applied to the symmetric tensor of second rank  $\psi^{ik}$  representing the gravitational field in Minkowski space.

The principle of equivalence can not be a foundation of the field approach because this principle eliminates gravity force and state equivalence between inertial motion and accelerated motion under gravity ("natural state of free falling"). For instance this principle creates such puzzle as the radiation of an electric charge resting on a laboratory table in the Earth's gravity field due to equivalence of this frame to the constant acceleration of the table.

The basic concept of inertial frame is conserved in FTG and there is no equivalence between inertial and accelerated motion. Instead of principle of equivalence there is the *principle of universality* of gravitational interaction (see below Eq.10), which has explicit relativistic form. As a consequence of this principle all bodies fall with the same acceleration in the Earth's gravity field and so the principle of equivalence in this form is satisfied. Moreover all classical relativistic effects in weak gravitational field have the same values in both FTG and GR.

The concepts of gravity force and gravity field energy are tightly connected in FTG and they are relativistic quantum physical quantities. In FTG the energy is considered as primary and fundamental concept, at least for the reasons of quantum approach where one needs the energy of gravitational field for its quantization. The flat space background without curvature, expansion and contraction (i.e. without creation and disappearance of vacuum) plays a very important role, radically changing the gravitational theory itself.

In flat space-time Noether's theorem leads to conservation laws for energy, momentum and angular momentum, including gravitational field. Instead of Eq.1 we get in flat space

$$T_{i,k}^k = 0, \quad (2)$$

with ordinary partial derivative in place of covariant one. In FTG Eq.2 gives both conservation laws and equations of motion; in GR Eq.1 gives only the equations of motion.

The existence of the energy-momentum tensor (EMT) of gravitational field in its traditional form allows for the ordinary quantization of gravitational field in FTG. The resulting quanta — both real and virtual carry gravitational interaction between physical bodies and fill physical vacuum — flat Minkowski space-time. The local positive energy density of gravitational field excludes the existence of such hypothetical objects as black hole and time machines. This statement can easily be proved and has clear physical meaning (see section 5.3).

It should be stressed that Lagrangian formalism doesn't allow to get a uniquely defined form of EMT for any field. If  $T^{ik}$  is a EMT of the field, then any new tensor of the form

$$\hat{T}^{ik} = T^{ik} + \frac{\partial}{\partial x^n} \psi^{ikn}, \quad (3)$$

with arbitrary third rank tensor  $\psi^{ikn}$  satisfying the antisymmetry relation

$$\psi^{ikn} = -\psi^{ink}, \quad (4)$$

is also another EMT for the same field.

In the book of Bogolyubov and Shirkov (1976), ch. 12, sec. 2, authors remark that this ambiguity in EMT definition is the main reason why they do not consider the gravity theory. The main point is that EMT plays a role of the field source and should be uniquely defined, which requires to use additional physical conditions. For instance, there are following natural conditions for EMT: symmetry, positive field energy, zero trace for massless fields. All these conditions are fulfilled for electromagnetic field. In following chapters we discuss the problems arising in case of gravitation.

Note that there is another approach to gravity theory which try to connect flat Minkowski space and curved Riemann space by postulating the *principle of geometrisation*. According to this principle all kinds of matter moves in effective Riemann space, while Minkowski space actually exist. Such approach is called "Relativistic Theory of Gravitation" (RTG) and is developed by A.A.Logunov with collaborators (see e.g. Logunov (1987); Logunov, Mestvirishvili (1989); Genk (1995); Vyblyi (1996)).

The main difference between FTG and RTG is that the field approach does not use any geometrisation, but is based on the concept of quantum symmetrical tensor field which has positive localizable energy density (for static and free field) corresponding to positive energy of gravitons — mediators of gravitational interaction. The geometrical picture appears in FTG only as approximation in some classical problems. Below we shall consider the history and main results of the field approach to gravity.

## 3 Classical theory of tensor field

### 3.1 Works of Birkhoff and Moshinsky

Forty years passed since Poincaré for the first time had put forward an idea to build relativistic theory of gravitation before the first real step was made in its fulfillment. It was done by Birkhoff in his work "Flat space-time and gravitation" (1944) where he formulated the theory "independent of all ideas of curved space-time and of the corresponding Einstein's theory".

It was a phenomenological theory of symmetric tensor field  $\psi^{ik}$  in flat Minkowski space with metric  $\eta^{ik}$ . Birkhoff postulated the equations of field and motion in given field in the form:

$$\square\psi^{ik} = \frac{8\pi G}{c^2} T^{ik}, \quad (5)$$

$$\frac{dp_i}{ds} = -mc(\psi_{ik,m} - \psi_{km,i})u^k u^m, \quad (6)$$

where  $\square$  wave operator,  $T^{ik}$  is EMT of the field sources,  $u^i$  — 4-velocity and  $p^i = mcu^i$  — 4-momentum of the test particle with the rest mass  $m$  which drops out from both parts of Eq.6 (from here the notations of Landau and Lifshitz (1971) are used). All risings and lowerings of indexes are ordinary made with Minkowski tensor  $\eta^{ik}$ , for instance

$$\psi_i^k = \eta^{km}\psi_{im}. \quad (7)$$

Birkhoff noticed that if for gravitational potential we use the tensor (now known as "Birkhoff potential"):

$$\psi^{ik} = \varphi_N \text{diag}(1, 1, 1, 1), \quad (8)$$

with  $\varphi_N$  being classical Newtonian potential, we arrive to all known relativistic effects — light bending, gravitational frequency shift, advance of Mercury's perihelion. The price of it is the adoption that EMT of matter should be of the form

$$T^{ik} = \frac{1}{2} \rho c^2 \text{diag}(1, 1, 1, 1), \quad (9)$$

i.e., he postulated the super-hard equation of state  $\varepsilon = p$  with  $1/2$  as additional multiplier.

Obviously, such postulate and the absence of derivation of his equations from more general propositions were weak points of the suggested theory. This is why Weyl interpreted this fact in terms of impossibility to build consistent field theory of gravitation and inevitability of geometrical approach.

Next important step in building the FTG was made by Moshinsky in his work "On the interaction of Birkhoff's gravitational field with the electromagnetic and pair fields" (1950). He for the first time made detailed calculations of the main relativistic effects consistently using the interaction Lagrangian in the form:

$$\Lambda_{<int>} = -\frac{1}{c^2} \psi_{ik} T^{ik}. \quad (10)$$

In fact, Moshinsky was the first who formulated the *principle of universality* of the gravitational interaction (Eq.10), according to which all kinds of matter interact with gravitational field through its EMT. This principle is a key stone in field approach to gravitation and plays the same fundamental role as the principle of geometrisation does in geometrical description of gravity.

Starting from Birkhoff's potential (Eq.8) and the principle of universality (Eq.10) Moshinsky accurately calculated the effects of light bending, hydrogen atom energy levels shifts and gravitational corrections to electron's magnetic moment. However, at that time there was no satisfactory derivation of Birkhoff's potential itself and Moshinsky's paper passed practically unnoticed.

### 3.2 Works of Thirring and Kalman

First full and consistent formulation of the FTG as a theory of symmetric tensor field in Minkowski space was published in Thirring's paper "An alternative approach to the theory of gravitation" (1961). In the weak field approximation Thirring obtained the non-linear equations:

$$\square \psi^{ik} = \frac{8\pi G}{c^2} \left( T^{ik} - \frac{1}{2} \eta^{ik} T \right); \quad (11)$$

$$T^{ik} = T_{<m>}^{ik} + T_{<int>}^{ik} + T_{<g>}^{ik}, \quad (12)$$

where  $T^{ik}$  is the total EMT of the system, including gravitational field itself,  $T_{<m>}^{ik}$  is the EMT of matter,  $T_{<int>}^{ik}$  is the EMT of the interaction,  $T_{<g>}^{ik}$  is the EMT of the gravitational field,  $T$  is the trace of the total EMT.

The equation (11) differs from that of Birkhoff's Eq.5 in two ways: first, it contains the term  $1/2 \eta^{ik} T$ , second, there are corrections connected with the energy-momentum of the gravitational field.

Now, the Birkhoff's potential (Eq.8) can be accurately derived as a linear approximation of the Thirring's equations with the full EMT being equal to that of matter's one:

$$T^{ik} = T_{<m>}^{ik} = \rho c^2 \text{diag}(1, 0, 0, 0), \quad (13)$$

which corresponds to ordinary "dust-like" equation of state instead of super-hard one in original Birkhoff's formulation. This statement removed the main Weyl's objection against FTG.

Thirring, also for the first time, put a question about unique definition of the EMT of gravitational field in connection with calculations of nonlinear corrections in Eq.11. He showed that canonical form of gravitational field EMT possesses symmetry and yields positive value for energy density of static field, described with Birkhoff's potential (Eq.8):

$$T_{<g>}^{00} = \varepsilon_{<g>} = \frac{1}{8\pi G} (\nabla \varphi_N)^2 \frac{\text{erg}}{\text{cm}^3}, \quad (14)$$

Moreover, EMT of interaction gives a negative contribution to the energy density (note, that  $\varphi_N < 0$ )

$$T_{<int>}^{00} = \rho \varphi_N, \quad (15)$$

and the full energy of gravitationally bound system turns out to be less than the total rest energy of its constituting parts (see the discussion about this in Sokolov S.(1995) and Baryshev (1995b)). As we noted above, from the fact that the energy of gravitational field is positive it follows that there are no "black holes", but Thirring didn't notice this fact (see 5.3).

Unfortunately, an error occurred in Thirring's work — in deriving the equation of motion of test particles the variation of proper interval  $ds$  were not taken into account (see the equation (11) in Thirring's paper). This error was corrected in the work of Kalman "Lagrangian formalism in relativistic dynamics" (1961) where he got the equations of motion in tensor field which could be written in the form (see also alternative derivation of this equations in Baryshev,1986)

$$A_k^i \frac{du^k}{ds} = -B_{kl}^i u^k u^l, \quad (16)$$

where

$$A_k^i = \left(1 - \frac{1}{c^2} \psi_{ln} u^l u^n\right) \eta_k^i - \frac{2}{c^2} \psi_{kn} u^n u^i + \frac{2}{c^2} \psi_k^i, \quad (17)$$

$$B_{kl}^i = \frac{2}{c^2} \psi_{k,l}^i - \frac{1}{c^2} \psi_{kl}^i - \frac{1}{c^2} \psi_{kl,n} u^n u^i. \quad (18)$$

Equations (16) have the tensor form hence particles trajectories do not depend on choice of coordinates.

In static spherically symmetric field in post-Newtonian approximation it is enough to write the non-linear correction only for  $\psi^{00}$  component of Birkhoff's potential:

$$\psi^{00} = \varphi_N + \frac{1}{2} \frac{(\varphi)^2}{c^2}, \quad (19)$$

where  $\varphi_N = -GM/r$  is the Newtonian potential. Substituting the Birkhoff's potential (Eq.8) with correction (Eq.19) to Kalman equations (16) we arrive to the three dimensional form of equations of motion:

$$\frac{d\mathbf{v}}{dt} = - \left(1 + \frac{v^2}{c^2} + 4 \frac{\varphi_N}{c^2}\right) \nabla \varphi_N + 4 \frac{\mathbf{v}}{c} \left(\frac{\mathbf{v}}{c} \cdot \nabla \varphi_N\right). \quad (20)$$

Equation (20) gives for the advance of perihelion of a test particle:

$$\delta\varphi = \frac{6\pi GM}{c^2 a(1 - e^2)}, \quad (21)$$

which coincides with the known formula in GR. Together with Moshinsky's results on electromagnetic and spinor fields interacting with gravity field, this shows that classical relativistic effects have the same values in both GR and FTG.

An interesting consequence of the equation (20) is a possibility of generalisation of the old Galileo's experiment with free falling bodies. A new version of such Galileo-2000 experiment is based on the fact that gravitational acceleration and gravitational force acting on a test particle depend on velocity of the particle. For example, as it was shown by Baryshev & Sokolov (1983), rotating bodies with different values and orientations of angular momentum will fall down from a "drop tower" with different accelerations. And this is direct consequence of the principle of universality of gravitational interaction and simply means that gravity force depends on the velocity of test particle. Another version of this experiment is a weighing rotating bodies with a scale, where there is no a free falling but there is actual balance of gravity forces acting on two differently rotating bodies.

Kalman made a comparison of linear theories for scalar, vector and tensor fields and, for the first time, derived exact expression of EMT for interaction between test particles and gravitational field in linear approximation. He also got a general form of energy-momentum conservation law for the system consisting of particles plus field in the form:

$$\left[ T_{<m>}^{ik} + T_{<int>}^{ik} + T_{<f>}^{ik} \right]_{,k} = 0. \quad (22)$$

It is interesting that for pure vector field (electrodynamics) the conservation law can be written as

$$\left[ T_{<m>}^{ik} + T_{<f>}^{ik} \right]_{,k} = 0, \quad (23)$$

i.e. without EMT of interaction (Kalman, 1961).

### 3.3 Thirring and Deser about identity of GR and FTG

Characteristic feature of almost all works on FTG is that authors try to declare the identity of field and geometrical approaches. Thirring's article (1961) starts with: "The problem of gravity has been solved by Einstein in his general theory of relativity... Any further contribution in this field is necessarily pedagogical or interpretational." Namely the reference to Thirring gave the foundation for Zel'dovich and Novikov (1971) to state that field approach to gravitation is identical with GR.

However, reader can easily find out that Thirring's work deals only with the case of weak field where both approaches give the same results. The situation in strong field, where they differ profoundly, is not considered at all.

Thirring suggest to consider the sum of two tensors  $\eta^{ik}$  and  $\psi^{ik}$ , which can be interpreted as an effective Riemann space metric tensor

$$\hat{g}^{ik} = \eta^{ik} + \psi^{ik}. \quad (24)$$

It ought to be noted that this presentation is a secondary and approximate in the framework of FTG. The prime features of FTG are quantum gravitational field and its quanta — gravitons,



which cannot be eliminated with any choice of reference system. From this it follows that principle of equivalence in formulation analogous to the GR doesn't take place in FTG, though, as was shown by Thirring, the equality of inertial and gravitational masses holds in FTG exactly and is a direct consequence of the principle of universality (Eq.10).

Moreover, the definition (24) has one more shortcoming — it takes us beyond the basic suggestions of tensor analysis in flat space. Actually, if  $\hat{g}^{ik}$  is a tensor in flat space, then its covariant components should have the form:

$$\hat{g}_{ik} = \eta_{ik} + \psi_{ik}, \quad (25)$$

and its mixed components and trace are as follows:

$$\hat{g}_k^i = \delta_k^i + \psi_k^i, \quad (26)$$

$$\hat{g}_{ik}\hat{g}^{ik} = 4 + 2\psi + O(\psi_{ik}^2). \quad (27)$$

The true metric tensor in Riemann space must satisfy the following exact relations:

$$g_k^i = \delta_k^i, \quad (28)$$

$$g_{ik}g^{ik} = 4, \quad (29)$$

which differ from (26) and (27). To match this two distinct tensors are usually considered:

$$\hat{g}^{ik} = \eta^{ik} + \psi^{ik}, \quad (30)$$

$$\tilde{g}_{ik} = \eta_{ik} - \psi_{ik}, \quad (31)$$

which are considered as the components of one metric tensor in Riemann space.

Let us notice that in consistent FTG all quantities with upper and lower indexes belong to the same tensor, i.e. the geometrical object of the flat space. Thus there are no confusion in interpretation of co- and contravariant components and there is always possible to introduce global Cartesian coordinates. The existence of flat background metric radically distincts the FTG from GR which most clearly seen in strong gravitational fields. Thus, there no prove of identity between FTG and GR in Thirring's work, all what was done was the demonstration of possibility to introduce an effective Riemann space for weak gravitational field.

Deser (1970) summed up all the preceding attempts to derive full system of Einstein equations from linear equations for tensor field. The essence of his approach is an iterative procedure with consequent account for the EMT of gravitational field, obtained from Lagrangian of the previous step. It starts from free tensor field Lagrangian and postulated form of metric tensor:

$$g^{ik} = \eta^{ik} + h^{ik}, \quad (32)$$

which, as was mentioned above, is a deviation from the field theory.

The main disadvantage of iterations is that Lagrangian formalism doesn't allow to get a unique gravitational EMT, so there is an infinite set of different non-linear generalizations of linear tensor field equations.

In fact, Deser showed no more then it is possible to find such an expression of EMT which at the third iteration gives Einstein equations and in no way this leads to the conclusion about identity

of field and geometrical approaches, as was claimed in the book of Misner, Thorne, Wheeler (1977). Moreover, the essence of field approach suggests such a choice of gravitational EMT that satisfies zero trace (massless graviton) and positive energy density of gravitational field and namely these properties should be tested first. Deser's EMT does not satisfy these conditions. It is easy to demonstrate that positive energy requirement leads to radical difference of field approach from that of geometrical one (see 5.3).

## 4 Quantum theory of tensor field

Quantum field theory is a theoretical background for description of all known physical interactions (strong, weak, electromagnetic). Thus, the deeper understanding of electrodynamics became possible only after the quantum electrodynamics had been build. FTG deals with gravitation in the same way as other matter fields are described, so there is quite natural to suggest the existence of quantum gravidynamics, presenting gravitation on more fundamental level then classical relativistic theory.

The idea of physical vacuum — the flat Minkowski space filled with quantum fluctuations of all fields, including gravitational one, plays an important role in gravidynamics. In quantum theory Newton's gravitation is a result of virtual gravitons exchange between bodies, just as Coulomb law is a result of virtual photons exchange.

First works on quantization of tensor field appeared in 30-es in articles of Rosenfeld (1930) and Bronshtein (1936). Different kinds of quantum formalism were used to calculate quantum gravity effects in works of Ivanenko & Sokolov (1947); Gupta (1952); Feynman (1963); Zaharov (1965); Weinberg (1965).

All these works actually dealt with the tensor symmetrical field in Minkowski space. Feynman (1971) in his "Lectures on Gravitation" emphasized that "The geometrical interpretation is not really necessary or essential to physics". The whole spirit and formalism used in these works refer them totally to the field theory of gravitation, though authors always speak about general relativity. In fact, the only feature they use from geometrical approach is a formal expression of Lagrangian and they give its expansion for the case of weak field.

The main problems of quantum gravidynamics are the physically grounded choice of Lagrangian and choice of gravitational EMT which cannot be fixed with Lagrangian. Still, there is an unresolved problem with quantum-field divergences. Another difficulty is connected with the absence of experiments on quantum gravity, due to smallness of expected effects, which makes it much harder to proceed the theory. Let us note, in this connection, the recently suggested experiment for measurement of the frequency dependence of gravitational bending of light by planets (Baryshev, Raikov (1995); Baryshev, Gubanov, Raikov (1996)), which could detect a quantum effects even in weak gravity field. An important possibility of non-zero rest mass of the graviton has been considered by Visser (1998). A possibility of existence a scalar component of gravitational field was discussed recently by Damour (1999).

## 5 Modern problems in field theory of gravitation

At the end of this review we list the most important, to our point, problems of field approach to gravitation. Their solution in near future could make a new step in understanding the physics of gravitational interaction.

## 5.1 Multicomponent tensor field

Quantum field theory requires to take into account both real and virtual gravitons. In general case, there are 10 independent components in symmetrical tensor field of the second rank  $\psi^{ik}$  and it is a superposition of particles with spins 2, 1, 0, and 0' which are involved in virtual processes

$$\{\psi^{ik}\} = \{2\} \oplus \{1\} \oplus \{0\} \oplus \{0'\}. \quad (33)$$

The gauge invariance of the gravitational field equations gives 4 conditions, eliminating the particles with spins 1 and 0' and leaving only 6 components, with spins 2 and 0. At the same time, the field source also consists of two parts

$$\{\psi^{ik}\} = \{2\} \oplus \{0\} \leftrightarrow \{T^{ik}\} = \{2\} \oplus \{0\}. \quad (34)$$

In particular, the BirkhgoFF potential (8) can be presented as a superposition of pure tensor (spin 2) and scalar (spin 0) parts

$$\psi^{ik} = \psi_{<2>}^{ik} + \psi_{<0>}^{ik} = \varphi^{ik} + \frac{1}{4} \eta^{ik} \psi = \varphi_N \text{diag} \left( \frac{3}{2}, \frac{1}{2}, \frac{1}{2}, \frac{1}{2} \right) + (-2\varphi_N) \frac{1}{4} \eta^{ik}. \quad (35)$$

Substituting (35) in equations of motion of the test particle (16) we arrive to conclusion that the total gravitational force, acting on the particle with rest mass  $m$  is the sum of attraction force (spin 2) and repulsion force (spin 0), which gives us the observed Newton force of gravity:

$$F = F_{<2>} + F_{<0>} = -\frac{3}{2} m \nabla \varphi_N + \frac{1}{2} m \nabla \varphi_N = -m \nabla \varphi_N = F_N. \quad (36)$$

Thus, the FTG is, strictly speaking, the scalar-tensor theory, already containing the scalar part in an initial tensor's trace (in contrast to the Brance-Dikke theory which requires additional scalar). The division of tensor potential into components is a new physical problem and it requires additional investigation.

## 5.2 Choice of energy-momentum tensor of gravitational field

An important problem of the choice of such gravitational EMT which satisfies the physical requirements of positive energy and zero trace arise, since Lagrange formalism does not allow to fix it in unique form. The multicomponent character of gravitational field contributes additional difficulties. The total Lagrangian is composed of attraction (spin 2) and repulsion (spin 0) terms contributing to the canonical form of the EMT with different signs and, thus, leaving the question about the sign of the energy of free particles opened. The division of gravitational EMT into two parts corresponding to spins 2 and 0 and having positive energy was for the first time made by Sokolov, Baryshev (1980). Further discussion and different forms of EMT can be found in works Baryshev (1982); Baryshev& Sokolov (1983); Baryshev (1988); Baryshev (1990); Sokolov (1992a, b, c, d); Baryshev (1995a).

There are two relativistic effects known until now, which could be used to set restrictions on the form of EMT — the pericenter advance in two-body problem and gravitational radiation. Both effects can be accurately measured in double pulsar PSR1913 + 16. Shift of pericenter indicates that energy density of static gravitational field coincides with the value given by Eq.14 with parts of percent

accuracy. The observed energy loss is consistent with radiation of quadruple waves and fixes the value of  $T^{00}$  component with spin 2.

The most accurate observations of *PSR1913 + 16* (Taylor et al., 1992) revealed the existence of about 1% excess in energy losses which could be interpreted as a scalar gravitational radiation with spin 0. Different forms of EMT give different values of the expected excess: 3% Baryshev (1982); 2.2% Sokolov (1992a); 0.735% Baryshev (1995a). For the final decision there are required improvement of measurements accuracy and account for possible non-gravity effects.

### 5.3 Absence of black holes in FTG

It is a fact of history, that Einstein and Eddington were opponents to the existence of black holes and suspend the development of the corresponding theory for almost 30 years (see Bernstein, 1996). Einstein's argument against black holes was very simple. Since Laplace it was known that for the body with radius less than  $R_g$  escape velocity exceeds that of light. Einstein (1939) actually inverted the Laplace's argument when he noticed that in this case the velocity of a test particle falling on such a body also exceeds the speed of light and this contradicts the special relativity theory. Einstein considered the gravitational radius as the limiting size of any physical body.

Later it was shown that in GR this argument doesn't hold, because inside  $R_g$  the space is not static. However, in FTG the space is everywhere flat and static, so the Einstein's argument is valid.

Eddington in his famous discussion with Chandrasekhar about the fate of white dwarfs with masses over the critical one, stated that there should be the law of nature preventing the contraction of massive stars under their gravitational radius.

It is easy to show that there is such a law in FTG and it is the law of conservation of energy! Indeed, if the energy density of static spherically symmetrical field of the body with mass  $M$  and radius  $R_0$  is given by  $T^{00}$  component of the gravitational EMT (14), then the full energy within the field around the body is

$$E_{<g>} = \int_{R_0}^{\infty} \varepsilon_{<g>} dV = \frac{GM^2}{2R_0} \text{ erg.} \quad (37)$$

It follows from here that there is a natural limit of contraction of a body and it is the condition that the energy of the field should be less than that of the rest-mass energy of the body:

$$\text{from } E_{<g>} < Mc^2 \text{ follows } R_0 > \frac{GM}{2c^2}. \quad (38)$$

Thus, the black holes are prohibited by the energy conservation. This statement is precisely analogous to that of the classical radius of electron  $R_e > e^2/m_e c^2$ , following from requirement that field energy  $E_{<el>}$  should be less than that of electron rest mass energy  $m_e c^2$ .

Let us consider another important consequence of the positiveness of gravitational energy density (14). Non-linear character of gravitational equations are naturally connected with energy of field itself and its sign give us two possible generalizations of the Laplace equation

$$\Delta\varphi = 0 \quad (39)$$

for gravitational potential around the body with mass  $M$ . In FTG gravitational field energy is positive, localizable and distributed around the gravitating body, so instead of Eq. 39 we get

$$\Delta\varphi = +\frac{1}{c^2} (\nabla\varphi)^2. \quad (40)$$

The solution of this equation with ordinary boundary conditions is

$$\varphi = -c^2 \ln \left( 1 + \frac{GM}{c^2 R} \right), \quad (41)$$

or for the force acting on unite test mass

$$\frac{d\varphi}{dR} = \frac{GM}{R^2 (1 + GM/c^2 R)}. \quad (42)$$

From (42) it follows that under  $R \rightarrow R_m \approx GM/c^2$  gradient of potential is confined with

$$g_{<max>} \leq \frac{c^4}{GM} = \frac{c^2}{R_m} \quad (43)$$

Hence according to FTG the force of gravity not only remains finite, but it decreases up to zero with infinitely increasing mass.

If we had negative static field energy density, as in the case of  $T^{00}$  component of the Landau-Lifshitz pseudo-tensor ( $\varepsilon_{<g>} = -7(\nabla\varphi)/8\pi G$ ), then we would have instead of (39)

$$\Delta\varphi = -\frac{1}{c^2} (\nabla\varphi)^2. \quad (44)$$

with solution

$$\varphi = -c^2 \ln \left( 1 - \frac{GM}{c^2 R} \right), \quad (45)$$

and force

$$\frac{d\varphi}{dR} = \frac{GM}{R^2 (1 - GM/c^2 R)}. \quad (46)$$

In this case the force becomes infinite independently of mass as the radius approaches to  $R \approx GM/c^2$ , just as we have in GR.

In FTG gravitational field energy is always positive and there are no problems with infinities. These simple physical considerations demonstrate the importance of EMT in gravitational physics and radical change of theory with change of the sign of field energy.

## 5.4 Astrophysical tests of FTG

Laboratory experiments can deal only with very weak gravity fields, but there are astrophysical objects where fields are extremely strong and where differences between geometrical and field theories should manifest themselves clearly.

Observations of double pulsars give information about relativistic dynamics of two body problem, including the loss of energy via gravitational radiation. A detection of gravitational waves from supernovae explosions by means of third generation antennas will give us a chance to establish their character (transverse for spin 2 and longitudinal for spin 0 waves), to get restrictions on EMT of gravity field and also to study physics of gravitational collapse (see Baryshev, 1997).

Observations of double X-ray sources with compact massive components will give clue to problem whether there are real singularities or the saturation of gravitational interaction takes place. Frequently one finds in literature that black holes have already been detected, because there are systems with

components more massive than the Oppenheimer-Volkoff limit, i.e. over the three solar masses. This statement is not correct, since this limit exists only in GR, but in FTG there could exist relativistic stars with larger masses. The discussion on this subject can be found in Baryshev, Sokolov (1984); Baryshev (1990; 1991); Sokolov(1992a,b,c,d); Sokolov,Zharikov (1993).

Cosmology is another field of application of gravitation theory. Present data about large scale galaxies distribution contradict to the main point of Friedmann cosmology — its homogeneity. It turned out that galaxies form a fractal structure with dimension close to 2 at least up to the distance scales bout 200 Mpc. This leads to a new possibilities in cosmology (see an analysis of FTG cosmological applications in the review of Baryshev et al., 1994). One of the main difference between FTG and GR is that the field approach allows the existence of the infinite stationary matter distribution (Baryshev, Kovalevskij, 1990). In a stationary fractal distribution the observed redshift has gravitational and Doppler nature and is not connected with space expansion as in Friedmann model.

## 6 Conclusions

The retrospective analysis of field gravitation theory is given and it is shown that field and geometrical approaches lead to quite different conclusions in strong fields. Which way "is a way to temple" will be clear from future astrophysical observations.

The central problem of geometrical description of gravity is the problem of "non-localizability" of the energy of the gravitational field or uncertainty of its value. In contrast the field gravity theory gives local, positive and observable value for the energy of the gravitational field, which could be used for quantum approach to gravitational interaction.

The field theory of gravitation is based on the principle of universality of gravitational interaction and has some forms of the principle of equivalence as its particular cases. In FTG there are Minkowski background space and usual concepts of gravity force, gravity field EMT and quanta of gravity field - gravitons. Within FTG there is no infinite force at gravitational radius and compact massive stars could have masses much more than OV-limit. FTG is actually a scalar-tensor theory and predicts existance of tensor (spin 2) and scalar (spin 0) gravitational waves. Astrophysical tests of FTG will be available in near future. It is quite natural that fundamental description of gravity will be found on quantum level and geometrical description of gravity may be considered as the classical limit of quantum relativistic gravity theory.

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